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G1G GPGA G6R
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(54) **An electromechanical sensor device and a method of manufacturing it**

(57) An electromechanical sensor device, which may be e.g. of piezoelectric, piezoresistive, or capacitive type, comprises an active wafer 12 having a metallised connection level 30, and an electric connection wafer 10 bearing electric interconnecting tracks or levels 18,20,24. The levels or tracks on the two wafers are secured together by solder balls 26 and optionally a solder bead 28. A mechanical sensing element is cut in the active wafer. The device can be used to make a pressure sensor, gyrometer or accelerometer. As shown the wafer 12 is covered by a protective cap 14. Several devices may be formed on wafers which are then diced.

FIG.1.

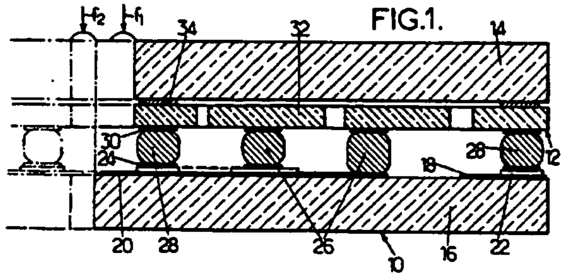
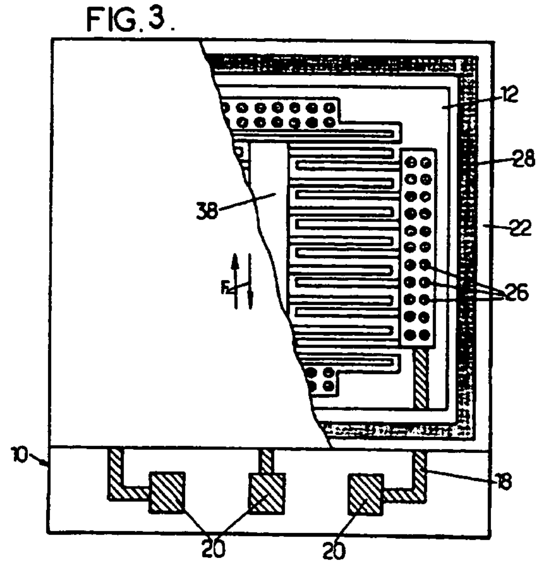


FIG.3.



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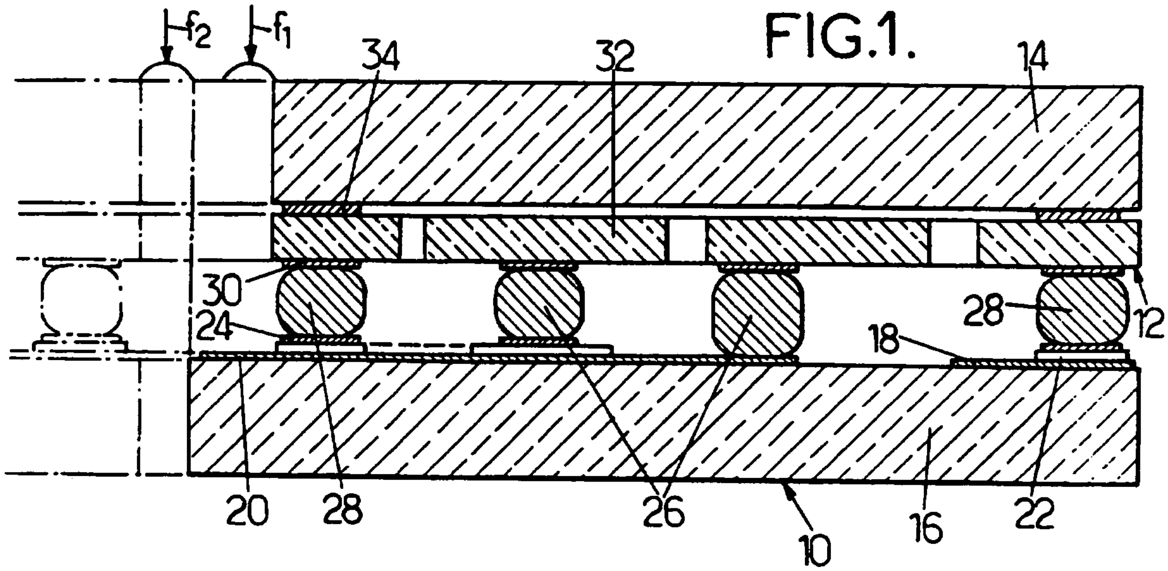
f2
f1
34
32
14
30
24
28
18
28
12
20
28
26
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16
22

FIG.1.

FIG.3.

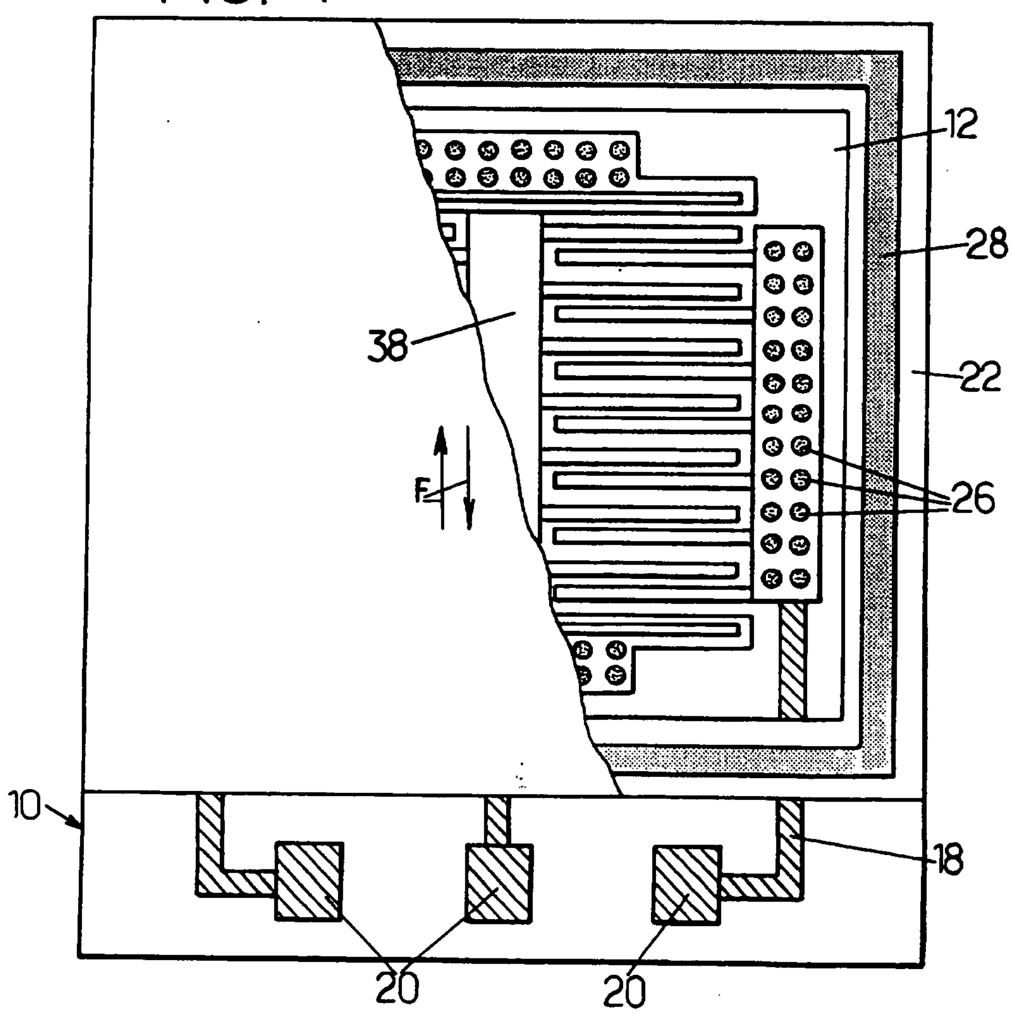

12
28
38
22
F
26
10
18
20
20

FIG.2.

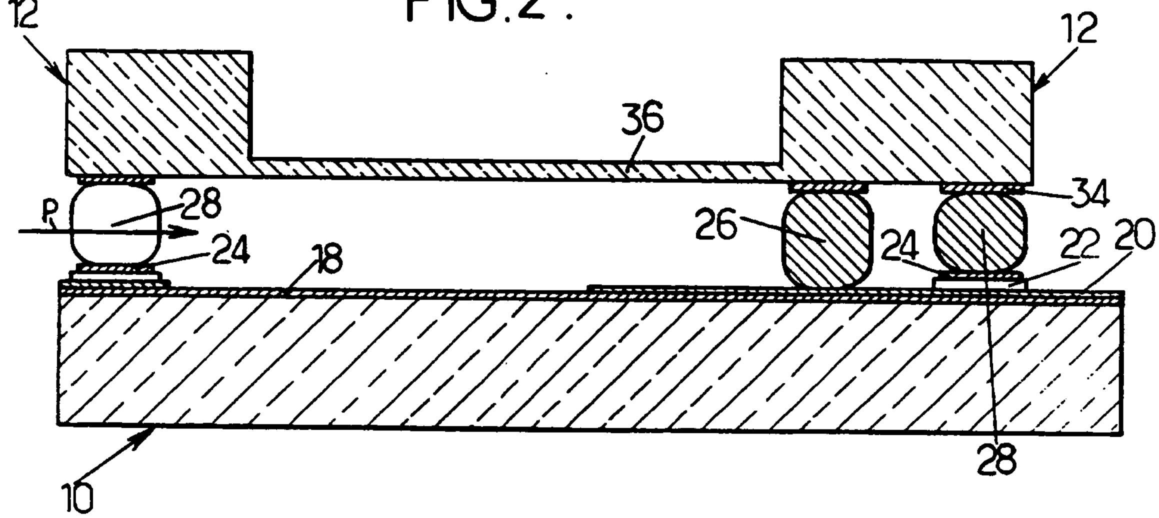
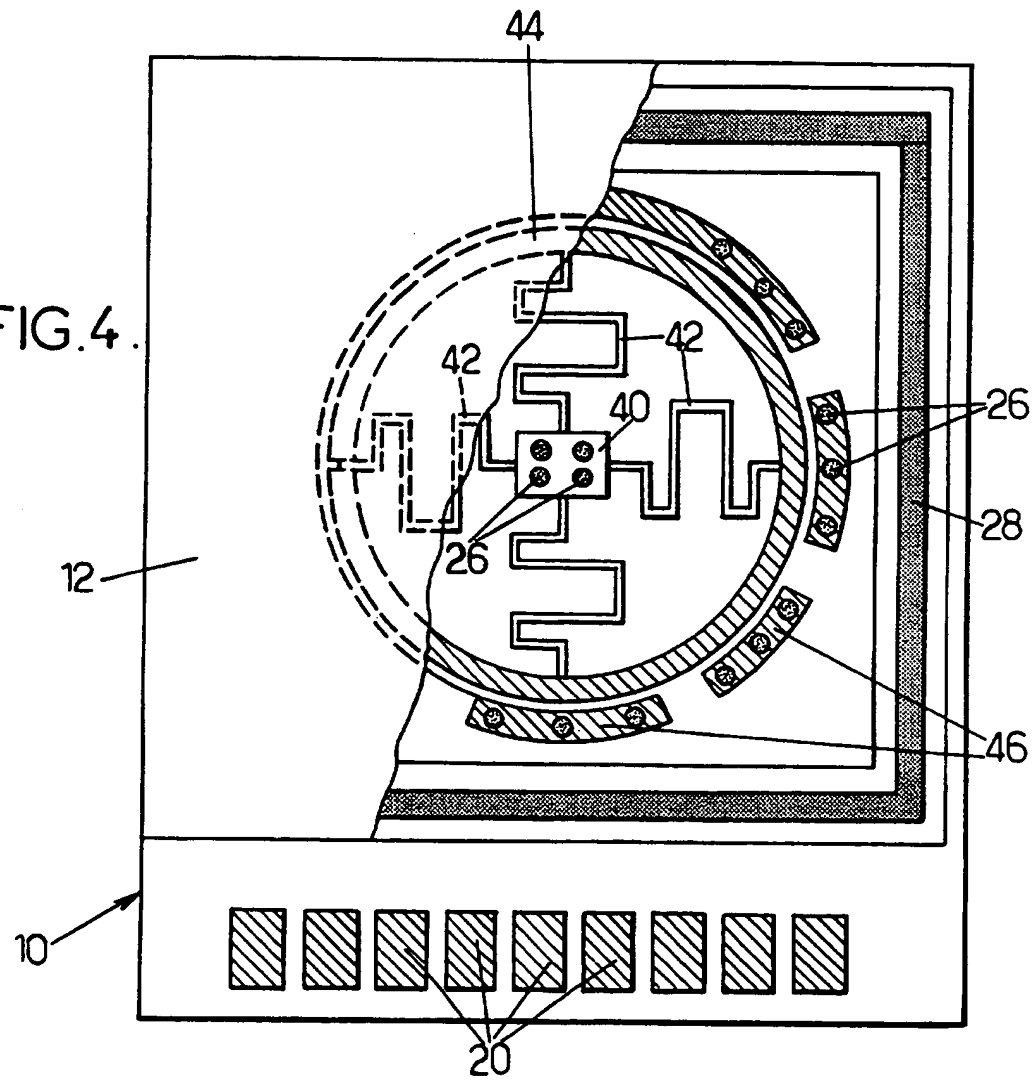

12
12
36
34
28
P
24
26
24
22
20
18
28
10

FIG.4.


44
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AN ELECTROMECHANICAL SENSOR DEVICE AND A METHOD OF MANUFACTURING IT

The invention relates to measuring devices comprising an electromechanical sensor, usually miniaturised, cut from a wafer formed with electric interconnecting tracks for conveying the signals occurring during measurement. The invention is applicable to devices for measuring physical parameters capable of stressing or deforming an active part of the sensor, inter alia pressure, acceleration and speed-of-rotation measuring devices such as those used on vehicles.

Some already-known sensor devices comprise an active wafer from which a mechanical sensor is cut and on to which interconnecting tracks are deposited and also comprise a wafer bearing electrical connections and areas for connecting to the exterior, a wafer which may be described as "passive". The electric connections between the wafers, and attachment of the wafers to one another (inter alia when the space between the wafers has to be sealed) are brought about in separate operations by techniques which result in considerable wastage.

The invention aims to provide a sensor device which can be miniaturised and meets practical requirements better than those previously known, inter alia in that it can be constructed in simple manner and with high efficiency.

To this end, the invention provides inter alia an electromechanical sensor device comprising:

- an electric connection wafer bearing electric interconnecting tracks,

- an active wafer from which the mechanical sensor is cut and which comprises an interconnection level facing the electric connection wafer, and

- means for electrically connecting and securing together the two wafers, comprising point contact balls and, if required, a bead surrounding the mechanical sensor and the balls, the balls and the bead being made of an electrically conductive soldering material.

In general the interconnecting tracks on the electric connecting wafer comprise a substrate bearing a first interconnection level forming output studs and a second interconnection level separated from the first by a dielectric layer. The first interconnection level can thus be separated from the bead by the dielectric layer and used to form output studs on a part of the electric connection wafer which extends beyond the active wafer.

Often, the bead will be adapted to form a sealing barrier between the exterior and a space containing the actual mechanical sensor. In other cases on the contrary, e.g. for a pressure measuring device, a passage will be formed in the bead or in one of the wafers.

The sensor device can also comprise a hood for protection against the external environment and attached to the active wafer e.g. by an adhesive.

The electric connecting substrate can be of various materials, such as monocrystalline silicon, ceramics or glass which is resistant to the temperature at which the securing means are formed. The wafer can even be in the form of a specific-application integrated circuit.

The invention also aims to provide a method of manufacturing a sensor device wherein a large number of devices can be collectively manufactured on a single substrate strip and subsequently cut out and separated.

To this end, the invention provides inter alia a method of manufacturing an electromechanical sensor wherein:

- electric interconnecting tracks in the form of at least one level are constructed on a first wafer;

- drops and a bead of solder are deposited on the electric connecting wafer at places for connection to the active wafer;

- the wafers are connected to one another by melting in vacuo or in an inert or reducing atmosphere, by heating and cooling so as to produce

electric connections and attachment and interconnection between the wafers, and

- finally an active wafer is made by cutting out a mechanical sensor and depositing an interconnection level.

The said features and others will become more apparent from the following description of specific embodiments of the invention, given by way of non-limitative examples. The description refers to the accompanying drawings, in which:

Fig. 1 is a section showing the basic construction of a device according to a specific embodiment of the invention and adapted to form an accelerometer;

Fig. 2, which is similar to Fig. 1, shows part of a device for forming a pressure sensor;

Fig. 3 is a top view, with partial removal of the active wafer, of an accelerometer constituting a specific embodiment and

Fig. 4, which is similar to Fig. 3, is a diagram of a device forming a vibrating gyrometer.

The sensor device, the basic construction of which is shown in Fig. 1, comprises an electric connecting wafer 10 and an active wafer 12 covered by a protective cap 14. The electric connecting wafer 10

shown in the drawing comprises a substrate 16. In the case of a miniaturised device, the substrate will generally be monocrystalline silicon, but other materials can be used. More particularly, use can be made of a substrate made of quartz or glass resistant to the soldering temperature or even ceramics. A miniature device will usually be made by using a monocrystalline silicon substrate 500 to 600 µm thick and surfaced with a film of insulating oxide.

The electric connecting wafer 10 in the embodiment shown in Fig. 1 comprises two metallisation levels. The first level 18, which can be made by one of the conventional present-day methods such as photolithography, comprises outlet studs 20 for connecting an external circuit. It is a few µm thick.

A thin dielectric layer 22, e.g. of oxide or nitride or more usually a dielectric resin such as a polyimide is deposited or formed on the first level 18. The dielectric layer 22 is then formed, by an optionally conventional etching process, with openings for interconnection with the second metallisation level or with electric connecting means described hereinafter.

The second metallisation level 24 can have a similar construction to the first. The level 24 is a few µm thick. To allow subsequent fixing it has a composite structure. In particular it may have successive deposits of titanium nickel and gold a

few micrometres thick. The first level can have the same construction. The deposit can be made e.g. by cathode sputtering.

After masking by a resin if required, a layer of soldering material is formed locally, for subsequently forming the electric and mechanical connecting means. Use can be made inter alia of a masking resin which serves as a resist varnish for defining the zones where solder is to be deposited. The solder can be made of tin and lead as conventionally used, with a melting point around 200°C to 300°C (60/40 or 95/5 tin-lead alloy). The composition can be deposited by electrolysis.

The balls 26 and the bead 28 for subsequently making the connections are obtained by re-melting and cooling the solder in vacuo in an inert or slightly reducing atmosphere (e.g. a nitrogen or N_2H_2 atmosphere). The surface tension during cooling results in the shape of a ball or a bead.

The thickness of the deposit and the size of the base of the studs and of the bead are chosen so that the balls have a diameter of 10 to 100 µm and the bead is 20 to 30 µm thick.

The second wafer 12, which is prepared separately, is shown in Fig. 1 in its state after machining. This wafer, like the first wafer, is made from a substrate, the nature of which will vary with the effect which is to be used (inter alia piezo-resistive, piezo-electric or capacitive). A

metallisation level 30 is deposited on the substrate by a method which can be the same as used for the wafer 10.

The two wafers 10 and 12 are then secured to one another in alignment. To this end the surface is first treated, e.g. by cathode sputtering. The two wafers are then placed in contact and sealed by heating to the melting-point of the solder and cooling in vacuo in an inert or slightly reducing atmosphere.

Fig. 1 shows cantilever portions 32 which are anchored by one or more lines of balls. Cutting can be by litho-photographic processes followed by anisotropic etching, e.g. reactive ionic etching. The structure can e.g. be one of those described in French Patent Applications 92 02782 and 95 08447, to which reference may be made.

One advantage of the construction which has been described is that a large number of devices can be made collectively from substrate wafers, e.g. of silicon. The active wafer can be machined after securing together, which results in a rugged assembly (e.g. by lapping down to a thickness of a few tens of µm followed by chemical etching of the upper surface and/or reactive ionic etching).

As shown by broken lines in Fig. 1, the metallisation and insulation patterns are then reproduced at regular intervals on the chips before assembly and final sawing apart.

In that case it may be necessary to protect the devices by a cap 14. This is because the sealed chips are cut, one above another, while being sprayed with de-ionised water. Since the distances between the moving parts and the fixed parts are small, the capillarity forces may damage the active parts during subsequent drying.

This risk is avoided by providing a wafer comprising all the caps 14 and stuck by a film of adhesive 34 to each zone of the plate for conversion into a wafer 12. The cut can then be made in two phases. During the first phase, a partial cut in the direction of arrow f1 separates the contact studs 20. A second cut along f2 through the cap and the two chips separates the devices.

Fig. 2, where components corresponding to Fig. 1 are denoted by the same reference numbers, shows a part of the wafers 10 and 12 of a device for forming a pressure sensor.

In that case, the active wafer 12 is made thinner locally to form a deformable diaphragm 36. In that case, before etching, the wafer (or the entire chip in the case of collective manufacture) is mechanically lapped and polished. Both surfaces often have to be polished in the case of collective manufacture, in order to etch alignment marks for subsequent accurate relative positioning of the wafers before sealing.

Once the thickness of the wafer 12 has been reduced to a few tens of micrometres, the thin diaphragm 36 can be made by chemical etching of the upper part or by reactive ionic etching.

The two wafers are secured to one another as previously described. However the sealing bead 28 will leave a gap giving access to the reference pressure as indicated by arrow P. The deformation of the diaphragm 36 can be measured by one of the methods known at present, e.g. by capacitive or piezo-resistive or even piezo-electric measurement.

The drawing shows only the sealing bead and one securing ball. Other connections will be provided between the active element and the outlet areas 20, on that part of the wafer 10 which projects laterally from the wafer 12.

The wafers will normally be made of the same material, or of materials having substantially equal expansion coefficients, to avoid thermal stresses.

Fig. 3 is a diagram of a sensor device for measuring acceleration in the direction of arrows F. In Fig. 3, components corresponding to those in Fig. 1 are as before denoted by the same reference number.

The electric connecting wafer 10 has the previously-described structure. Before the active wafer is assembled, it is provided with the metallisation levels, the balls of soldering material 26 and the bead 28. The active wafer can be made from a

monocrystalline silicon chip having the standard thickness of 500 or 600 µm. The wafer can be lapped and polished after securing to the interconnecting wafer, to reduce its thickness to 10 to 30 µm. The seismic mass and the arms connecting it can be cut out by methods already used for micro-machining of silicon throughout its thickness, e.g. by wet etching or anisotropic dry etching, which gives sides perpendicular to the faces. Any parts of the active wafer separated from the rest are held by the balls 26.

In the case illustrated in Fig. 3, the accelerometer comprises a central seismic mass 38 connected by flexible arms, obtained by cutting, to two lateral parts forming a pedestal. This construction will not be described in detail since it is one of those conventionally used for constructing miniature accelerometers.

Fig. 4 is a diagram of a sensor device in the form of a vibrating gyrometer. The active wafer has a central securing stud 40 secured to the interconnecting wafer by balls 26 connected to a cylindrical seismic mass 44 by cut-out arms forming suspension springs 42. Additional balls 26 disposed at the periphery connect the outputs 20 to fixed detection and excitation electrodes 46. In the case illustrated, nine output studs 20 are provided. Eight studs correspond to circumferential electrodes and the ninth corresponds to the electrode connected to the stud 40.

As can be seen, the invention provides sensor devices comprising a wafer micro-machined to obtain a structure which is deformable in the plane of the wafer or perpendicularly thereto and is e.g. in the form of a beam or diaphragm. The structure is mechanically anchored and electrically connected to a second wafer forming an interconnection substrate and can be completely protected from the external environment, leaving directly accessible electric contact areas.

C L A I M S

1. An electromechanical sensor device comprising

- an electric connecting wafer having a structure bearing electric interconnecting tracks;

- an active wafer from which a mechanical sensor is cut and comprises a metallised interconnecting level opposite the electric connecting wafer ;

- means for electrically connecting and securing together the two wafers, comprising point contact balls and a bead surrounding the mechanical sensor and the balls, the balls and the bead being made of an electrically conductive soldering material.

2. A sensor device according to claim 1, wherein the active wafer is smaller than the electric connecting wafer so as to give access to electric output studs provided on the electric connecting wafer.

3. A sensor device according to claim 1 or 2, wherein the wafers comprise a substrate made of monocrystalline silicon, quartz, glass or ceramics, the electric connection wafer optionally being a specific-application integrated circuit.

4. A device according to claim 3, wherein the interconnecting tracks on the electric connecting wafer comprise a substrate bearing a first interconnection level forming output studs and a second interconnection level separated from the first by a dielectric layer .

5. A device according to any of claims 1 to 4, wherein the bead is interposed between the facing surfaces of the wafers and forms a sealing barrier between the exterior and a space containing the actual mechanical sensor.

6. A sensor device according to any of claims 1 to 5, comprising a cap for protection against the external environment and secured to the active wafer by an adhesive.

7. A device according to any of the preceding claims, wherein the active wafer is cut so as to form an accelerometer or a gyrometer for measurement by capacitive, piezo-electric or piezo-resistive effect.

8. A method of manufacturing an electromechanical sensor device wherein:

- electric interconnecting tracks in the form of at least one interconnection level are made on a first substrate in order to form an electric connection wafer ,

- an active wafer is prepared in a second substrate and by deposition of an interconnection level ,

- balls and a bead of solder are deposited on the electric connection wafer at places for connecting to the active wafer,

- the wafers are connected to one another by melting in vacuo or in an inert or reducing atmosphere by heating and cooling, so as to obtain electric connections and attachment between the wafers, and

- construction of the mechanical sensor is completed.

9. A method according to claim 8, wherein the active wafer is lapped and polished after the active wafer has been secured to the connection wafer .

10. A method according to claim 8 or 9, wherein a number of devices are collectively manufactured by simultaneously forming the electric interconnecting tracks on the connecting wafers on a first chip, the balls and beads of solder for all the devices on the said first chip are deposited, the interconnection level of the corresponding active wafers is formed on a second chip and the active wafers are collectively machined before cutting the chips apart.

11. A method according to claim 10, wherein after the devices have been separated, an additional chip for forming the caps is secured to the first two chips which have already been secured to one another, the resulting stack is cut without touching the first chip, and the devices are then completely separated.

12. An electromechanical sensor device substantially as described hereinbefore with reference to the accompanying drawings and as shown in the drawings.

13. A method of manufacturing an electromechanical sensor device substantially as described hereinbefore with reference to the accompanying drawings.

The Patent Office

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Application No: GB 9618781.0
Claims searched: 1-13
Examiner: M. G. Clarke
Date of search: 2 December 1996

Patents Act 1977
Search Report under Section 17

Databases searched:

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:

UK Cl (Ed.O): G1N NAGC3, NAGC4, NAGC8, NAGC9, NAGCR, NAGD3, NAGD4, NAGD8, NAGD9, NAGDR; G1G GPGA; H1K KRG

Int Cl (Ed.6): ------------

Other: Online: WPI

Documents considered to be relevant:

Category	Identity of document and relevant passage		Relevant to claims
A	GB2186438A	Marelli Autronica - whole document	
X	EP0147831A2	Honeywell Inc - whole document	1,8 at least
A	US5346857	assigned to Motorola Inc - see especially Fig. 2 and columns 3,4	

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
Y	Document indicating lack of inventive step if combined with one or more other documents of same category.	P	Document published on or after the declared priority date but before the filing date of this invention.
&	Member of the same patent family	E	Patent document published on or after, but with priority date earlier than, the filing date of this application.